NASA Composite Technologies for Launch Vehicles

Composites Materials and Manufacturing Technologies for Space Applications

Outline

- Why composites?
- Automated fiber placement (AFP)
- Composite Cryotank Technology Development (CCTD) Project
- Composites for large scale launch vehicles
- Concluding remarks

The National Aeronautics and Space Administration

Human Exploration and Operations

Space Technology

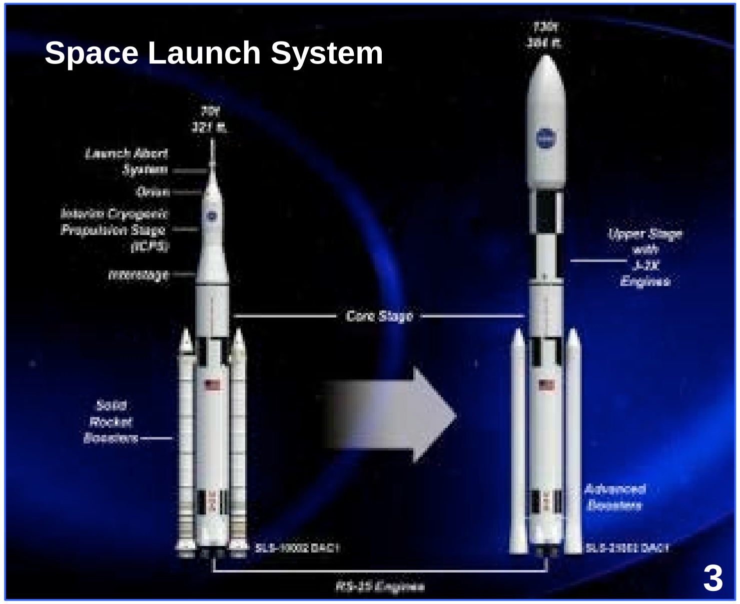
Science

Aeronautics Research

Marshall supports three of the NASA Mission Areas

Composites Support NASA and the Nation

- **All NASA Mission Directorates: Aeronautics Research, Human Exploration and Operations, Science, Space Technology**
- **Advanced Manufacturing National Initiative, and National Network for Manufacturing Innovation**
- **Other US Government Agencies: DOD, DARPA, DOE**
- **Identified in NASA Space Technology roadmap Technology Area 12 (Materials, Structures, Mechanical Systems & Manufacturing)**
- **Span multiple NASA Centers and disciplines**
- **Engage Industry and Research communities**



Financial Value of Reducing Launch Vehicle Structure Weight*

- **Value of eliminating pounds of structural weight is based on the cost of putting those pounds in space, which depends on:**
  - **Vehicle size**
  - **Where the structure is on the vehicle**
  - **Where the payload is going**
  - **Launch market conditions/launch contract details**
  - **Who makes the vehicle**
  - **How many pounds are being eliminated**
- **All of these factors vary but its agreed that $/lb to orbit is significant.**

Average Price Per Pound to Orbit for Launch Vehicles

Vehicle Class	LEO		GTO	
	Western	Non-Western	Western	Non-Western
Small	$8,445	$3,208	$18,841	N/A
Medium/Intermediate	$4,994	$2,407	$12,133	$9,843
Heavy	$4,440	$1,946	$17,032	$6,967

Futron Corporation Study, September 6, 2002

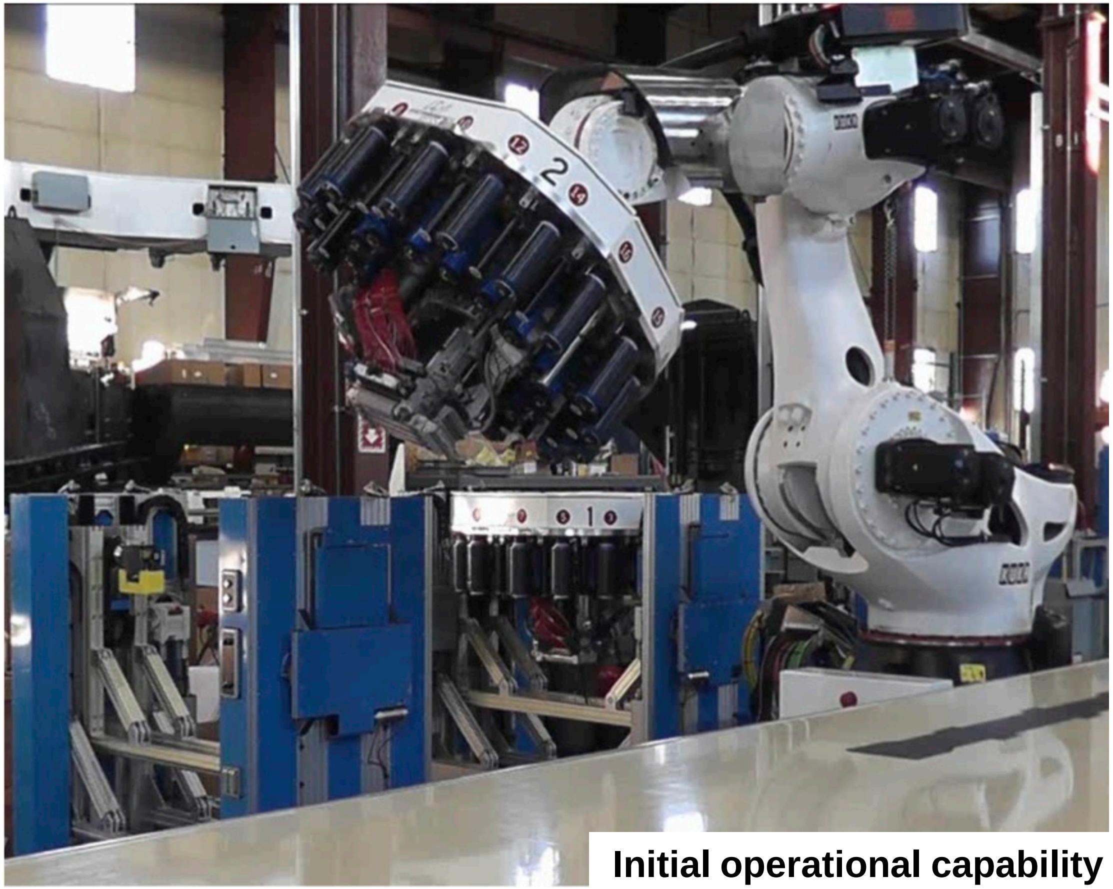
Canonical value often used: $10,000 per pound

*Mike Robinson Boeing

AFP Overview

- **Process developed in 1980’s**
- **Can apply either thermosets or thermoplastics, using prepreg materials in slit tape or tow forms**
- **Can perform fast, precise, accurate lamination on tooling, following preprogrammed paths**
- **Gaps, laps, twisted tows, fuzzballs, etc. are all par for the course**
- **Robotic mobility platforms are game changers, reducing entry cost by at least a factor of 2**

Flexible AFP System Architecture



Initial operational capability

Robot-based system allows multiple end effectors for assessing new composite materials, processes, structural concepts, manufacturing, and inspection techniques

Proposed end effectors include (clockwise from top): machining, grid-stiffening, and continuous tow shearing capabilities

Integrated Capabilities Across TRL* Range

*** TRL = Technology Readiness Level***

TRL 1-3

Develop
New Resins
and Fibers

Pre-Pregging of New
Composite Materials

Develop Advanced In-Process,
In-Situ NDE and Fabrication
Technologies

Basic Research

Applications

LaRC

MSFC

Technology Maturation

Manufacture
Launch Vehicle
Structures for
NASA Missions

TRL 7-9

Design, Build and Test
Proto-flight Structures

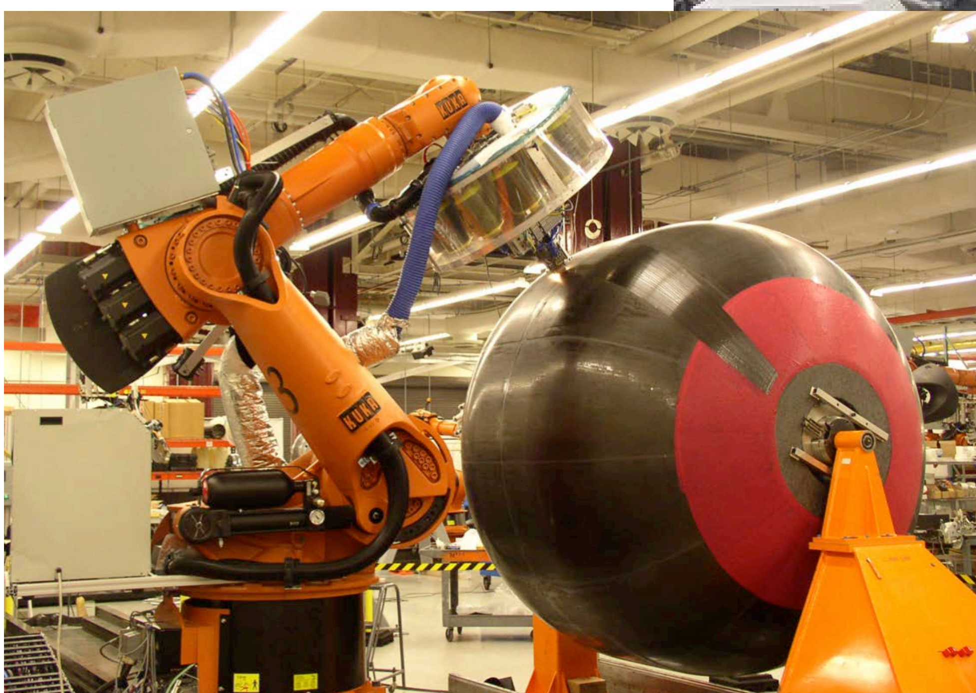
Post-Cure Characterization
and NDE of Composites

TRL 4-6

Design and Fabrication of
Advanced Structural Concepts

CCTD Project Composite Tanks

Design, build and test large prototype composite cryotanks for use on future launch vehicles



Two composite cryotanks (2.4-m and 5.5-m diam.) built using AFP, and tested at MSFC in 2014

CCTD Building Block Approach

TRL Definitions

Basic Technology Research:

Level 1: Basic principles observed & reported

Research to Prove Feasibility:

Level 2: Technology concept and/or application formulated

Level 3: Analytical and experimental critical function and/or characteristic proof of concept

Technology Development

Level 4: Component and/or breadboard validation in laboratory environment

Technology Demonstration:

Level 5: Component and/or breadboard validation in relevant environment

Level 6: System/subsystem model or prototype demonstration in a relevant environment

Development:

Level 7: System prototype demonstration in a space environment

System Test, Launch and Operations:

Level 8: Actual system completed and "flight qualified" through test and demonstration

Level 9: Actual system "flight proven" through successful mission operations

- **MRL/TRL Advancement**
  - **Prior to Project: 2-4 feasibility – technology development**
  - **After: 5-6 capability to model, design, manufacture and test subscale prototype hardware in a relevant environment demonstrated**
- **Production Environment Demonstrations:**
  - **Robotic automated fiber placement ~70% of structure**
  - **Multi-piece breakdown tool for one-piece pressure shell**
  - **Structurally efficient co-bonded and hot-bonded joints**

CCTD Project Test Results 2.4m

6/25/2013:

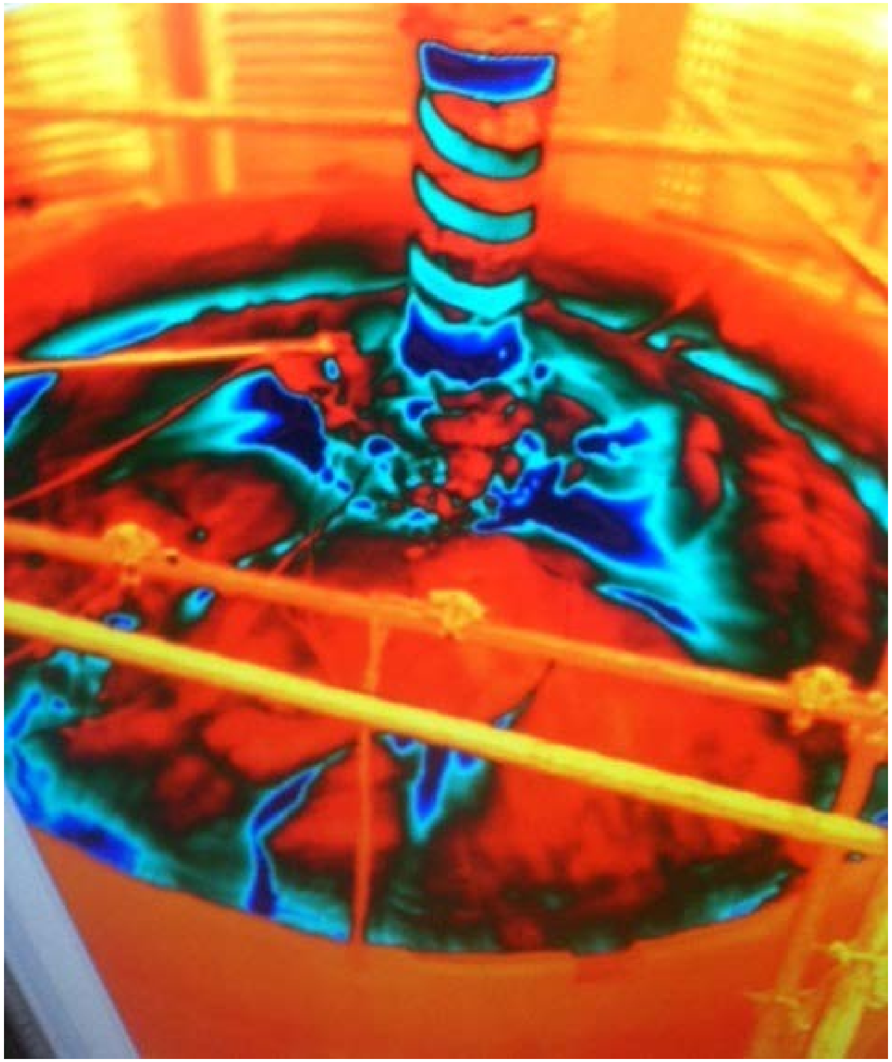
- **135 psi achieved with tank filled with LH2**
- **20 press./de-press. cycles between 20 psi & 100 psi conducted**
- **Permeation measurements conducted at multiple test conditions:**

7/25/2015:

- **100 press./de-press. cycles between 20 psi & 135psi conducted with LH2**

Future:

- **LH2 burst test at WSTF**



2.4m Thermal Image During LH2 Testing

CCTD Project Test Results 5.5m

Ground Test Program

1. Ambient Pressure
2. Cryogenic Pressure
3. Ambient Pressure & Mechanical
4. Cryogenic Cyclic Pressure

Ground Test Summary

- ✓ 83 pressure cycles
- ✓ 2 thermal cycles
- ✓ 2 max pressure cases
- ✓ 1 combined load cycle

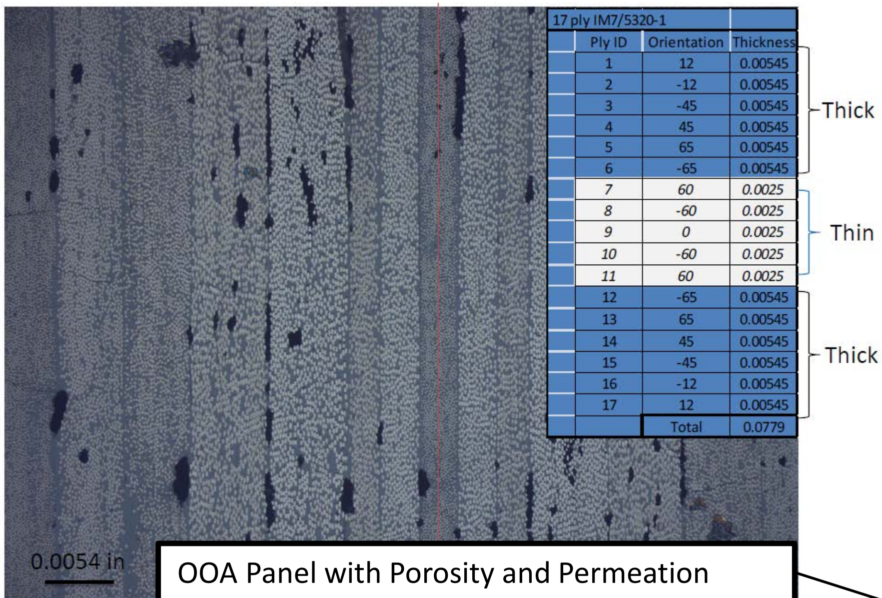
Data Acquired

- Load/strain response
- Thermal response
- Laminate permeation rate
- Bolted joint performance

Marshal Space Flight Center

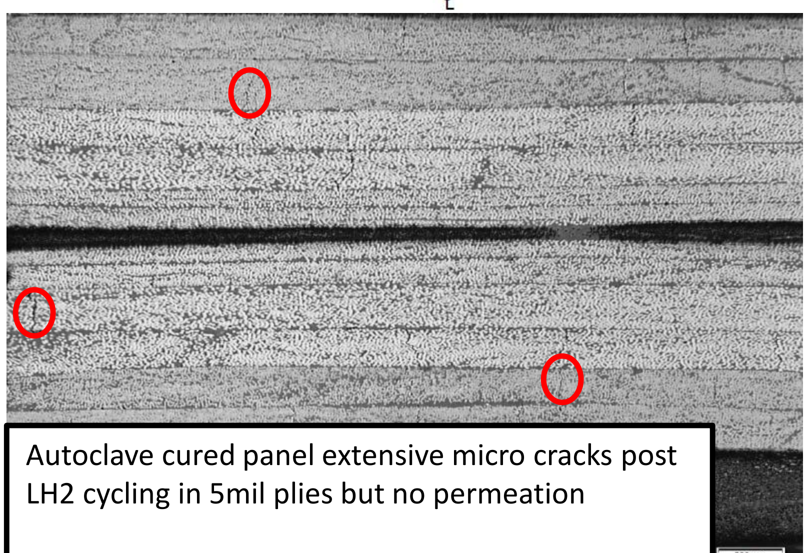
CCTD Project OOA AFP Lessons Learned

- **Micro cracks formed in thin plies primarily due to presence of porosity**
- **To eliminate permeation**
  - Increase number of thin plies
  - Reduce porosity
    - Autoclave cure
    - Improved OoA AFP processes

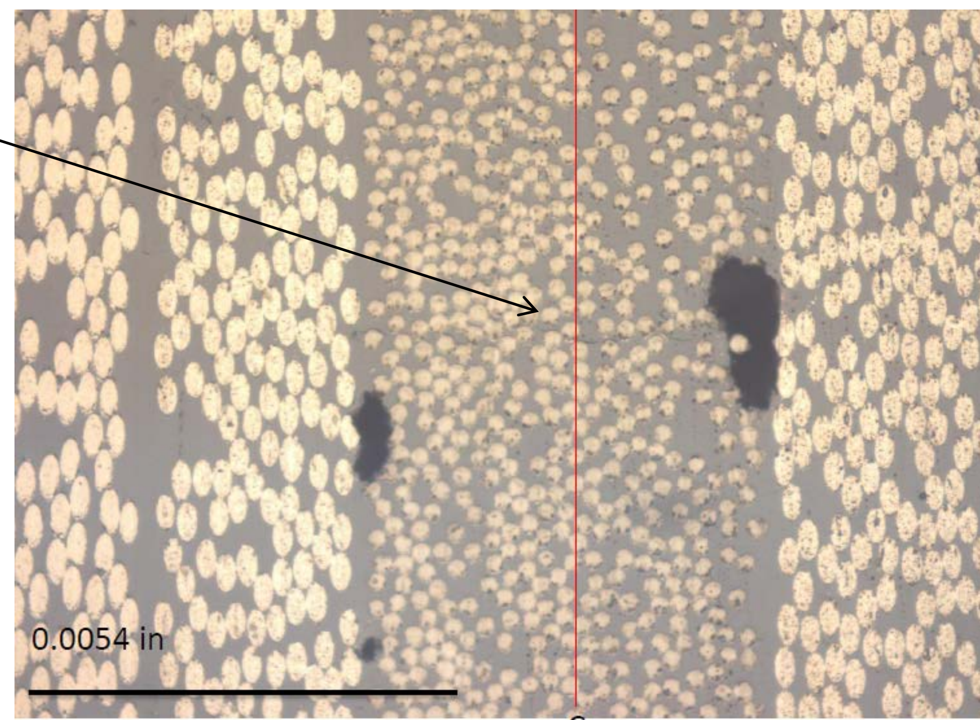


17 ply IM7/5320-1		
Ply ID	Orientation	Thickness
1	12	0.00545
2	-12	0.00545
3	-45	0.00545
4	45	0.00545
5	65	0.00545
6	-65	0.00545
7	*60*	*0.0025*
8	*-60*	*0.0025*
9	*0*	*0.0025*
10	*-60*	*0.0025*
11	*60*	*0.0025*
12	-65	0.00545
13	65	0.00545
14	45	0.00545
15	-45	0.00545
16	-12	0.00545
17	12	0.00545
	Total	0.0779

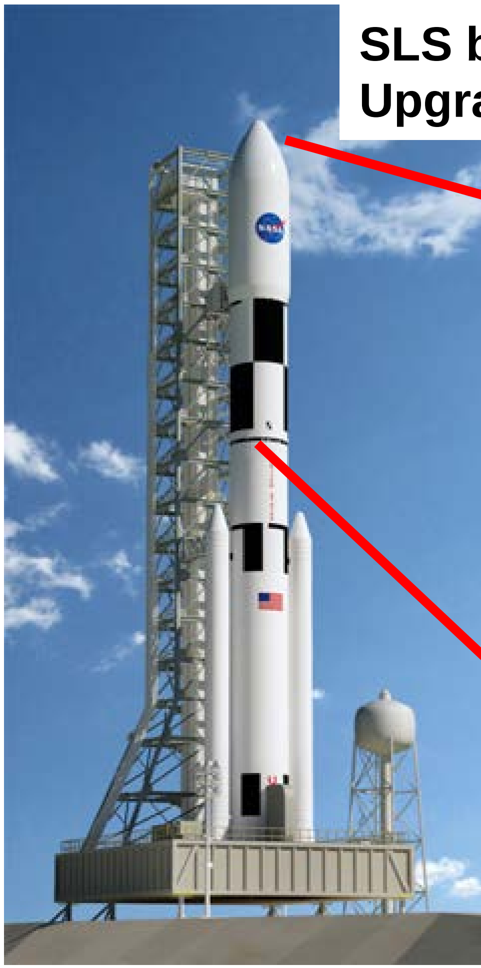
OOA Panel with Porosity and Permeation



Autoclave cured panel extensive micro cracks post LH2 cycling in 5mil plies but no permeation



Risk Reduction Large Scale Structures



SLS block IB
Upgrade (opportunities)

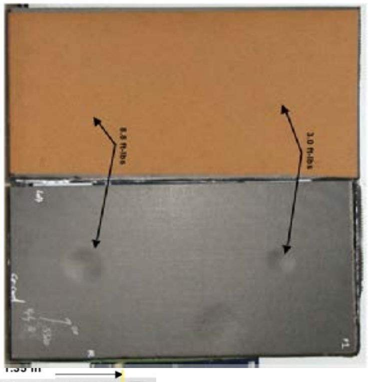
New Upper Stage

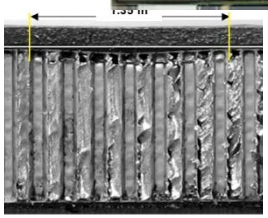
Design, build and test prototype composite skirts for future Space Launch System (SLS) upgrade

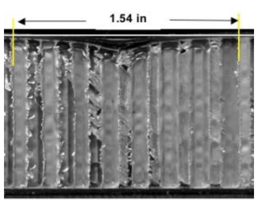
LaRC planning to build flat and curved panels for concepts, technology development and testing of structural joints

MSFC planning to build large curved panels for fabrication and testing of full-scale structural test article(s)

Risk Reduction Large Scale Structures







- **Assess possible accidental and fabrication induced damage threats**
  - For payload fairing blunt impact damage is the most likely type of accidental damage
- **Investigate effect of damage size with respect to structural scale**
  - Boundary conditions can affect the impact energy level necessary to produce a given size of damage.
- **Repair all detectable damage**
- **Demonstrate through element and sub-component testing that under simulated flight loads the structure is insensitive to undetectable size damage**

Test specimens were found to be insensitive to barely visible damage.

Concluding Remarks

- New robotic AFP platforms provide state-of-the-art composites capabilities for NASA Centers
- Flexible AFP system architecture allows development and implementation of advanced-capability end effectors
- AFP systems can support the full TRL spectrum from basic research to flight hardware
- With these AFP capabilities, LaRC and MSFC are well-positioned to support many NASA projects and programs